TECHNICAL NOTE:

BULK DENSITY, WATER CONTENT, AND HYDRAULIC PROPERTIES OF A SANDY LOAM SOIL FOLLOWING CONVENTIONAL OR STRIP TILLAGE

J. D. Jabro, W. B. Stevens, W. M. Iversen, R. G. Evans

ABSTRACT. *Tillage produces a more favorable soil physical environment for seed germination and plant growth. A 2-year study was carried out to compare effects of conventional (CT) and strip (ST) tillage practices on soil bulk density (ρ_b), water content (θ_w), final infiltration rate (I_r) and saturated hydraulic conductivity (K_s) for a Lihen sandy loam where sugarbeet (*Beta vulgaris *L.) was grown during the 2007 and 2008 growing seasons. Under each tillage system, we measured ρ_b and θ_w using soil cores collected from the center of crop rows in all plots at soil surface (0 to 10 cm) and 10-to 30-cm depths. At both depths under each tillage system, we measured* in-situ *I_r using a pressure ring infiltrometer (PI) and* in-situ *K_s using a constant head well permeameter (CHWP). Although we noted a significant difference in ρ_b between CT and ST plots at 10- to 30-cm depth in 2007, soil θ_w did not differ significantly between CT and ST plots in 2007. In 2008, soil ρ_b and θ_w did not differ significantly between CT and ST plots at both depths. The log-transformed I_r was affected by tillage practice at $P \le 0.1$ in 2007 but was not significantly affected in 2008. The effects of tillage on log-transformed K_s were significant at $P \le 0.05$ in 2007 and $P \le 0.1$ in 2008. Soil K_s values were 68% and 56% greater for ST than for CT in 2007 and 2008, respectively. We concluded that ST reduced soil compaction in the row, consequently increased total porosity, reduced ρ_b, and thereby increased I_r and K_s in the soil.*

***Keyword**. Bulk density, Infiltration, Hydraulic conductivity, Strip tillage, Sugarbeet, Soil compaction.*

Tillage is one of the most influential agricultural management practices affecting soil physical and hydraulic characteristics (Lal and Shukla, 2004). In this study, we introduced two types of tillage, the conventional tillage (CT), which consists of several separate operations using different tillage implements following the harvest of one crop in preparation for the next crop, and strip tillage (ST), which involves a single operation with specialized equipment (Evans et al., 2010) that provides alternating strips of tilled and untilled soil. Whether tillage is accomplished by CT or ST, the results of its application are unpredictable, and its effects on soil structure, macropore modifications, and other physical properties at the field scale are known to be contradictory (Lal and Van Doren, 1990; Coutadeur et al., 2002). Moreover, there is little information available regarding the effect of ST on soil physical and hydraulic properties.

Tillage has been shown to temporarily improve soil porosity by creating temporary macropores that consequently increase water movement in the soil (Ahuja et al., 1989; Ankeny et al., 1990; Bouma, 1991). On the other hand, tillage has been shown to destroy established aggregates and macropores and disrupt soil pore continuity, thus reduce water flow between the plow layer and subsoil (Bouma, 1991). Beneficial effects of tillage on pore size distribution are temporary because pore spaces that are created either collapse or are sealed during the growing season as a result of raindrop impact and wetting and drying cycles (Topaloglu, 1999). Such inconsistency of results demonstrates the need for additional studies regarding the effect of various tillage practices on soil physical properties.

Infiltration rate and saturated hydraulic conductivity are considered the most important parameters describing water flow and chemical transport phenomena in soils (Reynolds and Elrick, 2002). Hydraulic conductivity is affected by bulk density and effective porosity, two commonly measured physical properties of soil fundamental to soil compaction and related agricultural management issues (Strudley et al., 2008). While tilled soil has been shown to have a lower bulk density, higher effective porosity and superior K_s than non-tilled soil (Rosenberg and McCoy, 1992), tilled soils can also exhibited a higher bulk density, lower effective porosity, and inferior K_s than non-tilled soils (Chan and Mead, 1989; Dao, 1996).

In view of inconsistency of results and the lack of literature about the effect of ST on soil physical and hydraulic properties, objectives of our research were to compare the effects of both CT and ST on four important parameters--bulk density (ρ_b), gravimetric water content (θ_w), final infiltration rate (I_r), and saturated hydraulic conductivity (K_s)--in a

Submitted for review in February 2011 as manuscript number SW 9065; approved for publication by the Soil & Water Division of ASABE in May 2011.

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  ISSN 0883-8542

sandy loam soil of the Mon-Dak region (northeastern Montana and northwestern North Dakota), United States.

Materials and Methods

This research was extended for two additional years (2007 and 2008) to verify the conclusions stated in Jabro et al. (2009b). The research site was located at the Nesson Valley Mon-Dak Irrigation Research and Development Project, approximately 37 km east of Williston, North Dakota (48.1640 N, 103.0986 W). The soil is mapped as Lihen sandy loam (sandy, mixed, frigid Entic Haplustoll) consisting of very deep, somewhat excessively or well drained, nearly level soil that formed in sandy alluvium, glacio-fluvial, and aeolian deposits in places over till or sedimentary bedrock. Particle size analysis indicated the textural class of the surface horizon (0 to 30 cm) to be consistently within the sandy loam classification. The amount of sand, silt, and clay in the soil at the 0- to 30-cm depth ranged from 640 to 674, 176 to 184, and 150 to 166 g kg^{-1}, respectively.

The experimental design was a randomized complete block design with four replications at 0 to 10 cm and eight replications at 10- to 30-cm depth. Treatments used in this study consisted of CT and ST under sugarbeet (*Beta vulgaris* L.) using a linear-move overhead sprinkler irrigation system.

Soil I_r and K_s measurements were made approximately 1 m apart in the center of crop rows within CT and ST sugarbeet plots on 17-20 July 2007 and 9-12 July 2008. Using a soil core sampler, undisturbed soil cylindrical core samples (5 cm long × 5 cm in diameter) were collected from each plot at 0- to 10- and 10- to 30-cm depths for each tillage system. Soil cores were used to measure ρ_b as a mass of oven-dried soil per volume of core (Mg m^{-3}) and content θ_w as a mass of water in the soil sample per mass of the ovendried soil (g g^{-1}).

The total pore volume (ε) was for each soil depth increment was calculated:

$$\varepsilon = (1 - \rho_b/2.65) \quad (1)$$

where 2.65 Mg m^{-3} is the soil particle density.

The macropore volume (ε_m) was calculated as:

$$\varepsilon_m = \varepsilon - 0.228 \quad (2)$$

where 0.228 m^3 m^{-3} is the estimated water content at field capacity level for a Lihen sandy loam soil (Jabro et al., 2009a).

Each soil measurement was replicated four times. Soil I_r measurements were determined using the single-head pressure ring infiltrometer (PI) method (Reynolds and Elrick, 2002). The PI consisted of a Mariotte-type reservoir, similar to that of the constant head well permeameter (CHWP), sealed to a stainless steel ring with a radius of 10 cm and driven to a depth of 5 cm into the soil surface (Reynolds and Elrick, 2002).

Using a steady state flow rate of water from a cylindrical borehole augured to a given depth below the soil surface, the *in-situ* K_s was measured using a CHWP (Reynolds and Elrick, 2002). The I_r and K_s measurements were replicated four in each year. The measurements were made in the center of crop rows under each tillage system.

Tillage Operations

Conventional Tillage

Conventional tillage consisted of four separate operations using different tillage implements following malting barley (*Hordeum vulgare* L.) harvest prior to sugarbeet planting. The CT plots were tilled immediately prior to planting in the spring of 2007 and 2008. Plots were fertilized and disked 12 cm deep on 18 April 2007 and 18 April 2008. On 23 April 2007 and 22 April 2008, the plots were chisel-plowed with straight shovels to a depth of 16 cm. Two passes were made with a cultipacker (seedbed preparation implement) on 24 April 2007 and 25 April 2008. Sugarbeet seeds were planted on 24 April 2007 and 29-30 April 2008. Five herbicide applications were made in 2007; three herbicide applications were made in 2008 due to the use of a glyphosate-tolerant sugarbeet variety in 2008. Plots were cultivated between the crop rows on 4 and 21 June 2007 and on 2 July 2008 for weed control. Yield samples were hand collected on 24 September 2007 and 22-23 September 2008.

Strip Tillage

Strip tillage was performed with specialized equipment described in detail by Evans et al. (2010). The ST operation was completed 7 September 2006 and 20 September 2007 for the 2007 and 2008 crop years, respectively. Briefly, the six-row strip tiller (3.6 m width) was set to a depth of 20 cm with a straight coulter in front of a semi-parabolic shank followed by two wavy coulters and a crowsfoot packer wheel (Schlagel TP 6524, Schlagel Mfg., Torrington, Wyo.) that tills 30-cm strips and leaves 30 cm of standing stubble between tilled rows. A tube mounted on the rear of the shank placed dry fertilizer 10 cm deep in the tilled zone. The strip tiller was pulled with a 104-kW front wheel assist tractor (JD 7810, John Deere, Moline, Ill.). No additional field operations in ST were performed before planting. Spraying for weed and insect control, cultivating, and harvesting were performed on the same dates as for the CT plots.

Statistical Analysis

Soil I_r and K_s values for each year were checked for normality of distribution using SAS probit procedures (Littell et al., 1996). The I_r and K_s results for 2007 and 2008 presented in this article were found to be best described by a log-normal distribution. The logarithmic-transformed I_r and K_s values were then analyzed using the ANOVA of MIXED model procedure by SAS software (Littell et al., 1996). The statistical analysis was used to test the differences between treatments for soil physical and hydraulic variables for each of the two years. Treatment was considered as the fixed effect and replication as the random effect. Data were analyzed using a randomized complete block design. Statistical significant was evaluated at $P \le 0.05$, unless otherwise mentioned.

Results and Discussion

Soil ρ_b and θ_w did not significantly differ between CT and ST in either year with the exception of ρ_b in 2007 at 10- to 30-cm depth, which was significantly affected by tillage treatment at $P \le 0.05$ (table 1). Soil ρ_b was numerically greater in CT plots than in ST plots at 0 to 10 cm and 10- to

Table 1. Effect of tillage on soil bulk density (ρ_b), total pore volume (ε), macropore volume (ε_m), and gravimetric water content (θ_w) at 0- to 10- and 10- to 30-cm depths for CT and ST practices.

Year	Depth (cm)	Tillage	ρ_b (Mg m^{-3})	ε (m^3 m^{-3})	ε_m (m^3 m^{-3})	θ_w (g g^{-1})
2007	0-10	CT	1.561a[a]	0.411a[a]	0.183a[a]	0.0774a[a]
		ST	1.522a	0.426a	0.198a	0.0834a
	10-30	CT	1.642a[a]	0.380b[a]	0.152b[a]	0.0695a[a]
		ST	1.531b	0.422a	0.194a	0.0792a
2008	0-10	CT	1.515a	0.428a	0.200a	0.0994a
		ST	1.455a	0.451a	0.223a	0.1020a
	10-30	CT	1.586a	0.402a	0.174a	0.0905a
		ST	1.567a	0.409a	0.181a	0.0983a

[a] Means within given year and depth followed by the same letter are not significantly different at $P \leq 0.05$.

30-cm depths in both years, suggesting that the CT operations increased soil compaction due to frequent traffic passes induced for this tillage practice. Nevertheless, ST is perceived as having greater porosity and wetter soil conditions compared with CT (Licht and Al-Kaisi, 2005). Elimination of secondary tillage and more limited vehicular traffic in ST plots likely contributed to decreased ρ_b, in 2007, compared to CT plots as the ST system includes only a single in-row soil disturbance operation that decreases soil ρ_b and conserves water to a greater degree than the CT system (Licht and Al-Kaisi, 2005).

The log-transformed I_r and K_s under both CT and ST tillage systems in 2007 and 2008 are illustrated in figures 1 and 2, respectively. Results indicate that I_r was significantly affected by tillage at $P < 0.1$ in 2007 while I_r did not differ significantly between CT and ST practices in 2008 (fig. 2). Although variations in I_r between CT and ST practices existed in both years, these variations were not significant at $P \leq 0.05$ (figs. 1 and 2). However, the similarity in I_r between CT and ST at the surface suggests that the CT and ST tillage systems are similar in terms of soil disturbance at this depth (0 to 10 cm).

The effects of tillage on soil K_s were significant in 2007 at $P \leq 0.05$ and in 2008 at $P \leq 0.1$ (figs. 1 and 2). The K_s values were 68% and 56% greater for ST than for CT in 2007 and 2008, respectively. Results in table 1 and figures 1 and 2 showed that K_s increases as the ρ_b decreases and soil total porosity increases, indicating that soil compaction influences K_s measurements at the 10- to 30-cm depth. Overall, these findings agree with results reported by Jabro et al. (2009b),

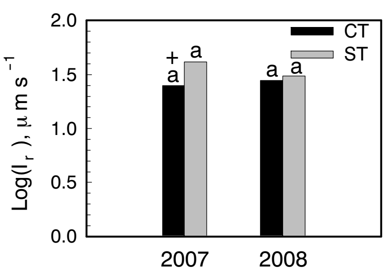

Figure 1. *In-situ* final infiltration rate (I_r) as affected by conventional tillage (CT) and strip tillage (ST) practices in 2007 and 2008. Within a given year, means are significantly different at $P \leq 0.05$ if letters above the bars are different. A '+' signifies that a difference is significant at $P \leq 0.10$.

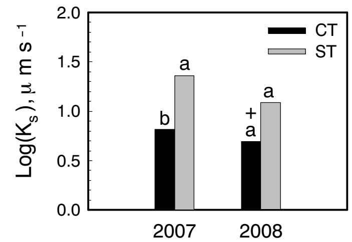

Figure 2. *In-situ* saturated hydraulic conductivity (K_s) as affected by conventional tillage (CT) and strip tillage (ST) practices in 2007 and 2008. Within a given year, means are significantly different at $P \leq 0.05$) if letters above the bars are different. A '+' signifies that a difference is significant at $P \leq 0.10$.

which indicate that greater K_s values correspond with lower soil bulk density values at the subsurface depths.

Results of this study suggest ST system reduced soil compaction compared to CT system, which consequently altered soil ρ_b and total porosity (ε), thereby increasing I_r and K_s in the soil (table 1, figs. 1 and 2). The compacted soil and higher ρ_b in CT rows were likely responsible for the lower I_r and K_s values compared with ST plots in both years. Moreover, the ST system likely produced a greater volume of macropores (Wienhold and Tanaka, 2000; Lipiec et al., 2005), resulting in more pronounced vertical pore connectivity in ST plots than in CT plots (table 1). As a consequence, water flow through the soil profile was greater in ST plots than in CT plots where the macropores discontinued as soil depth increased due to soil compaction developed from tillage in CT.

As mentioned earlier, the CT system consists of several more field passes of equipment in which the wheel traffic is not confined to the inter-row area (Jabro et al., 2009b). The tires contact approximately 30% of the width tilled by implements; as multiple passes are required to prepare the seedbed, it is probable that most of the plot area was influenced by at least one tire track. However, in the ST system, the wheel traffic was confined to the inter-row area where ρ_b, I_r, and K_s measurements were not taken (Jabro et al., 2009b).

The strip tillage operation creates a "V"-shaped tillage profile approximately 5 cm wide at the bottom and 30 cm wide at the top. Soil between the shanks on the strip tiller is not disturbed. The full width tillage operation is slightly shallower at 16-cm depth, but the shanks are only 30 cm apart so all of the soil is disturbed between the shanks. Power requirements and the economics for the tillage operations were beyond the scope of this study but have been quantified by others who found that fuel use was reduced by 40% in a corn-soybean rotation (Schnitkey and Lattz, 2006) to 53% in a cotton-cover crop-cotton sequence when strip till is compared to full width tillage (Mitchell et al., 2006). More information regarding energy use of tillage-related field operations can be found in Smith et al. (1995), Schnitkey and Lattz (2006), Schaefer (2007), and Overstreet (2009).

Other studies have shown yield and quality are generally not significantly different (Evans et al., 2010), nor is individual root weight statistically different between the two treatments (Stevens et al., 2009). Plant population was more likely to be different 10 to 20 days after planting than at harvest time, but no clear trend favoring one tillage system was established (Evans et al., 2010). The use of glyphosate tolerant sugarbeet varieties has greatly reduced weed control problems.

Summary and Conclusions

Soil ρ_b and θ_w did not significantly differ between CT and ST in either year with the exception of ρ_b in 2007 at 10- to 30-cm depth, which was significantly affected by tillage treatment at $P \leq 0.05$. Soil ρ_b was numerically lower in ST plots than in CT plots while θ_w was greater for ST than for CT at both depths in both years. Soil I_r was significantly affected by tillage at $P \leq 0.1$ in 2007 while I_r did not differ significantly between CT and ST practices in 2008. The effects of tillage on soil K_s were significant in 2007 and 2008 at $P \leq 0.05$ and at $P \leq 0.1$, respectively. The I_r and K_s values were greater in ST plots than CT plots in both years. The variation in K_s values was likely due to differences in soil compaction and wheel traffic passes peculiar to the CT and ST systems. The results of this study suggest ST system reduced soil compaction, consequently reducing ρ_b and thereby increasing I_r and K_s in the soil. The ST plots likely had larger volume of macropores than CT plots, producing greater water flow through the ST soil profile.

Acknowledgments

The authors would like to extend their sincere thanks to Mr. Dale Spracklin for his assistance in soil sampling and measuring soil physical properties. The authors also thank Mrs. Genevieve Gwynne for her excellent editorial remarks. The helpful suggestions and comments of the Editor, Dr. Kyle R. Mankin, Associate Editor, Dr. Mark Grismer, two internal reviewers and three anonymous reviewers are greatly appreciated. Their suggestions immensely improved the readability and quality of the article.

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